APPENDIX 21A

Fate and Behavior Modelling of Hazardous Materials Spill Report

Valentine Gold Project – Fate and Behavior Modelling of Hazardous Materials Spill

Final Report

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Sign-off Sheet

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Table of Contents

LIST OF TABLES

LIST OF FIGURES

Abbreviations

2D	two-dimensional
CCME	Canadian Council of Ministers of the Environment
DARM	Drainage Area Ratio Method
EC	Environment Canada
ECCC	Environment and Climate Change Canada
EIS	Environmental Impact Statement
FM	Flexible Mesh
ICMC	International Cyanide Management Code
MDMER	Metal and Diamond Mining Effluent Regulation
PT	Particle Tracking
the Project	Valentine Gold Project
WSC	Water Survey of Canada

1.0 Introduction

The Environmental Impact Statement (EIS) Guidelines for the Valentine Gold Project (the Project) issued by the Government of Newfoundland and Labrador (NL) call for "Fate and behaviour modelling of potential spills of hazardous materials, including hydrocarbons and sodium cyanide, to waters frequented by fish should be considered for all seasons" (Government of NL 2020). The Federal EIS Guidelines call for "Fate and behaviour modelling of potential spills of hydrocarbons, sodium cyanide and ammonium nitrate to waters frequented by fish should be considered for all seasons" (Impact Assessment Agency of Canada 2019).

In accordance with the Provincial and Federal EIS Guidelines for the Project, the following report evaluates the fate and behaviour of potential spills of diesel, sodium cyanide, and ammonium nitrate into the Victoria River, flowing into Red Indian Lake.

2.0 SPILL STUDY AREA

The Project Area (Figure 2-1) extends from the mine site to approximately 500 m south of the bridge crossing the Exploits River. The potential spill location is within the Project Area (along the access road) and proposed approximately 100 m upstream of the mouth of the Victoria River, at the bridge crossing where the river drains into Red Indian Lake. An accidental spill release of hazardous materials at the bridge crossing of the Victoria River is thought to represent a worst-case condition as it would affect the mouth of the river, Red Indian Lake, and potentially the Exploits River. Therefore, the study area focused on the 100 m extent of the Victoria River, approximately 14 kilometres of Red Indian Lake and the Exploits River Dam.

Red Indian Lake is located in the western interior of the Island of Newfoundland. The Victoria River, Lloyds River, Star River, Shanawdithit River, Buchans River, and Mary March's Brook River are the main watercourses flowing into the lake. The water level in the lake is controlled by the dam at the head of the Exploits River. The lake drains into the Exploits River, which exits into the Atlantic Ocean through the Bay of Exploits. In Figure 2-2, the model domain is shown with the red polygon.

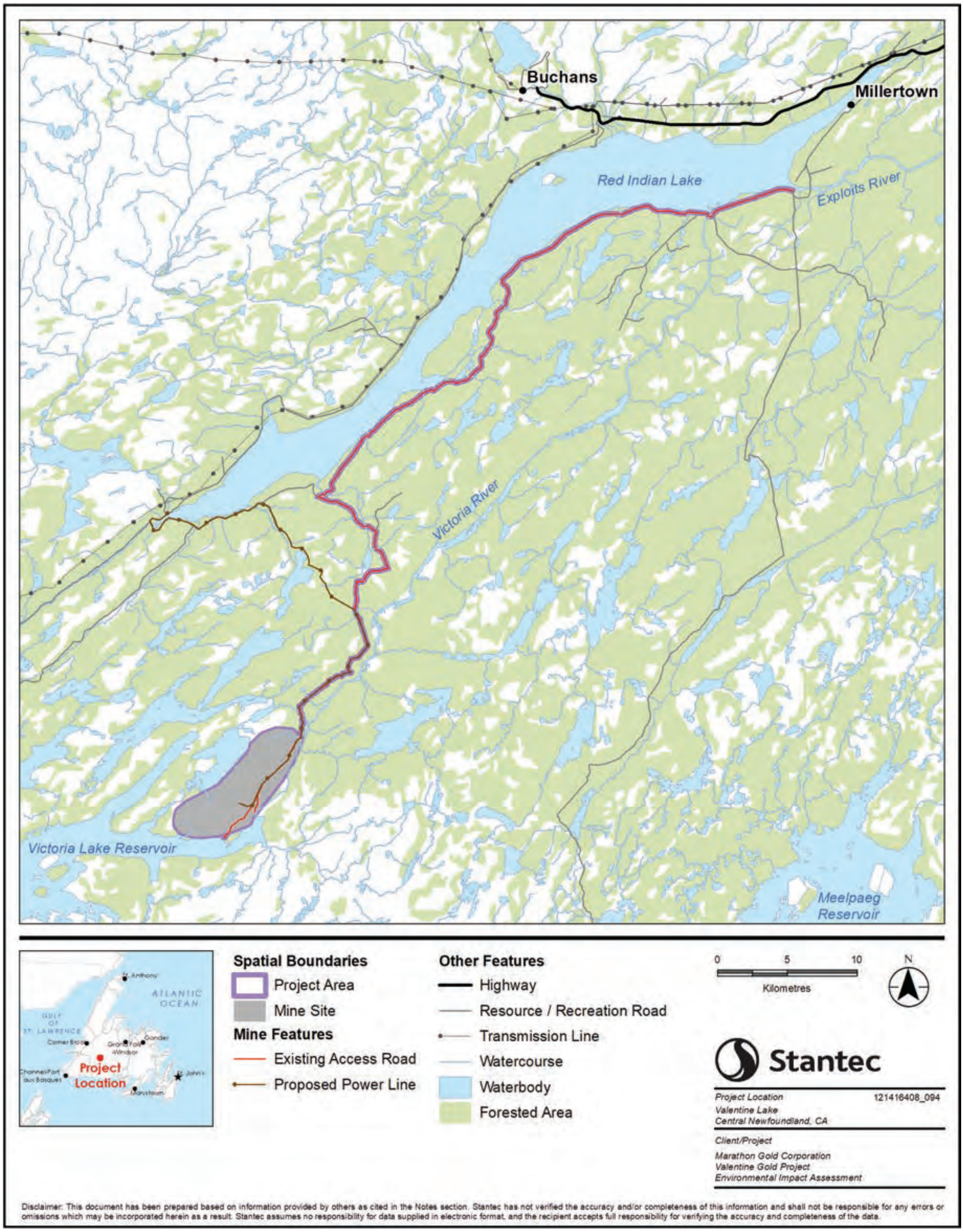

Figure 2-1 Project Area

Figure 2-2 Study Area

3.0 AMBIENT CHARACTERIZATION

3.1 AMBIENT WATER QUANTITY

Two Water Survey of Canada (WSC) stations are located within or in proximity to the study area. The WSC stations were used to characterize Red Indian Lake water levels and inflows into the lake. The WSC station 02YO017 has monitored the water level in Red Indian Lake at Indian Point since 2009. This station is approximately 3 km upstream of the Exploits River Dam. Historical records of outflow from the lake for the period of 2007 to 2020 are available at WSC station 02YO016 on the Exploits River near Millertown. Available provincial and federal records of water level and flow data were analyzed to evaluate low, seasonal, and high flow and water level conditions within the study area. The WSC station details are summarized in Table 3-1.

Table 3-1 Summary of WSC Monitoring Stations

Station ID	Name	Area (Km^2)	Agency	Data Record	Data Type
02YO016	Exploits River near Millertown	4810	WSC	2007 - 2020	Flow
02YO017	Red Indian Lake at Indian Point	N/A	WSC	2009 - 2020	Level

3.1.1 Red Indian Lake Water Levels

The water levels in Red Indian Lake are controlled by the Exploits River Dam at the outlet of the lake. The dam was constructed in 1909 as a reservoir control structure for the Grand Falls hydroelectric facility (Cole 1997). Historical lake water level data was obtained from WSC station 02YO017 on the Exploits River. Figure 3-1 shows the observed mean monthly, maximum and minimum daily water levels in Red Indian Lake. The water levels varied between 149.78 meters and 156.39 meters, with an average water level of 153.72 meters. Following the spring snowmelt, the mean maximum water levels occur in May and June. Daily water levels in the lake were analyzed to calculate seven-day low water levels in the lake. Figure 3-2 shows the results of the frequency analysis of seven-day low water levels in the lake. The instantaneous low water level was obtained from the WSC station 02YO017 for this analysis.

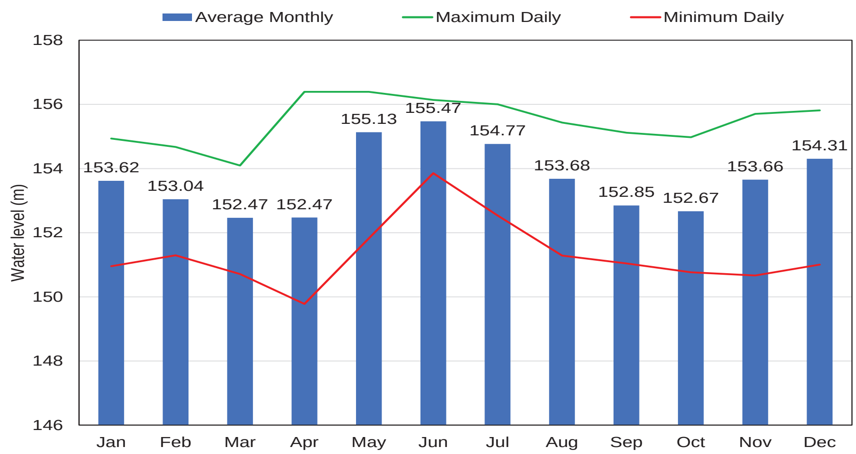

Figure 3-1 Mean Monthly and Maximum and Minimum Daily Water Levels in Red Indian Lake from 2009 until 2019

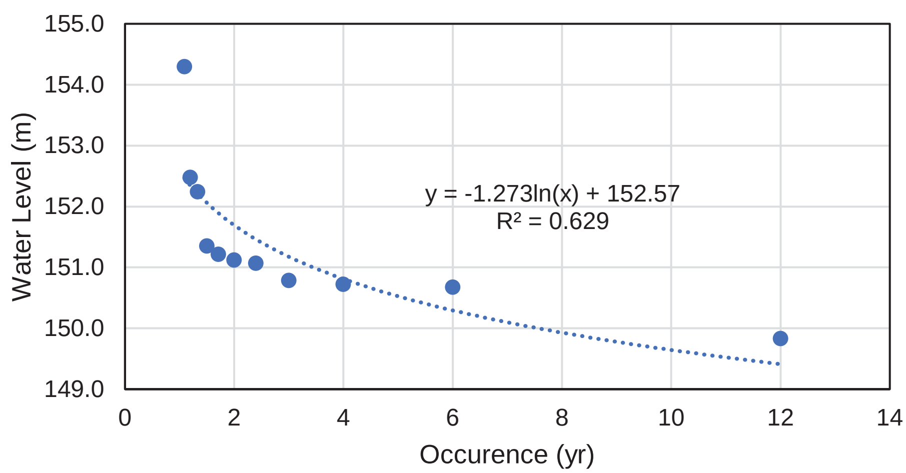

Figure 3-2 7-day Low Water Levels Frequency Analysis

3.1.2 Outflow from Red Indian Lake

Historical records of outflow from Red Indian Lake are available at WSC station 02YO016 on the Exploits River at the dam. The observed mean monthly, maximum and minimum daily discharge from the lake are summarized in Figure 3-3. The outflow values varied between 48.80 m^3/s and 1130.00 m^3/s with an average discharge of 153.95 m^3/s. Figure 3-4 and Figure 3-5 show the seven-day low-flow (7Q) and peak-flow frequency analyses based on instantaneous low and high flow data obtained from the WSC station 02TO016.

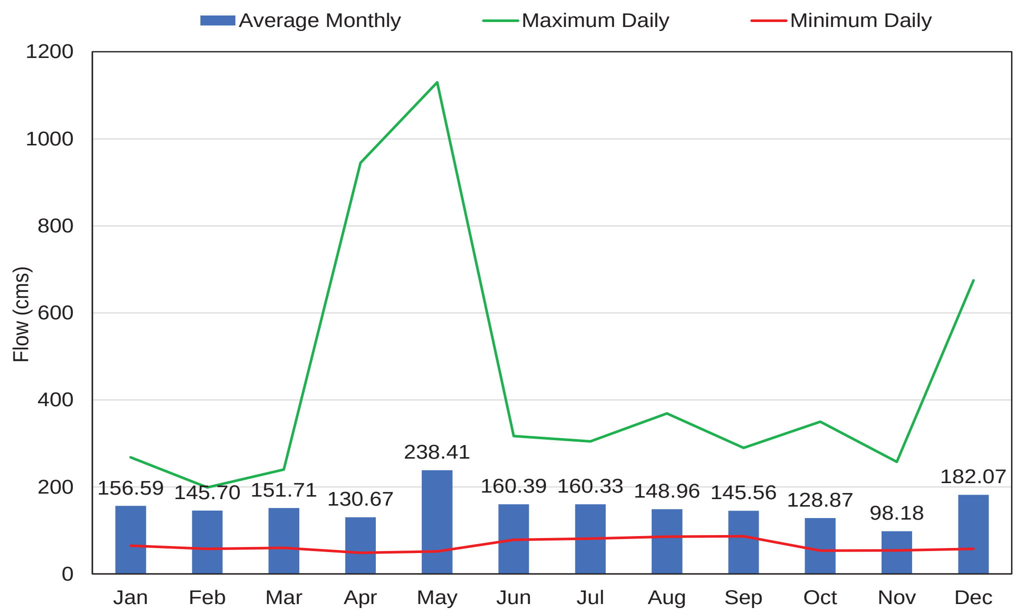

Figure 3-3 Mean Monthly and Maximum and Minimum Daily Water Levels in Red Indian Lake from 2009 until 2019

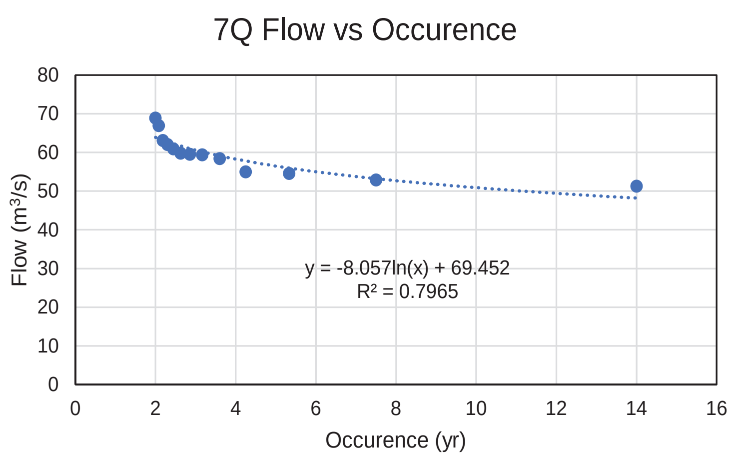

Figure 3-4 Low-flow Frequency Analysis

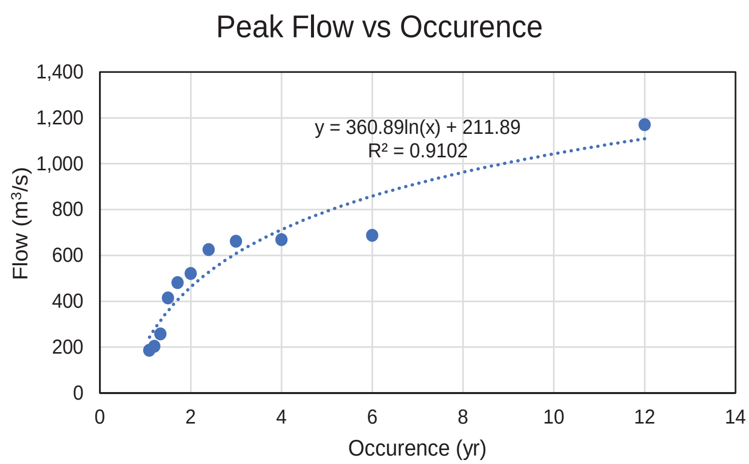

Figure 3-5 Peak-flow Frequency Analysis

3.1.3 Inflow to Red Indian Lake

To estimate the inflows to the lake from the watercourses flowing into the lake, the Drainage Area Ratio Method (DARM) was used to distribute the possible flow scenarios to each inflow sources using the ratio of the drainage area of the inflow watercourse to the total drainage area at WSC station 02YO016 (USGS 2005; Hirsch 1979). West inflow represents inflows to the lake from the Shanawdithit River, Lloyd's River and Star River, and East inflow accounts for inflows from the Mary March River to the lake. The locations of the rivers are shown in Figure 2-2. The inflow to the lake from each watercourse was then calculated by multiplying the estimated flow of each scenario to watercourses drainage area ratios. The watershed areas of the watercourses flowing into the lake are summarized in Table 3-2.

Table 3-2 Watershed Areas of the Watercourses Flowing into Red Indian Lake

River	Drainage Area (km^2)
Victoria River	549
Mary March River	616
Star River	448
Shanawdithit River	427
Lloyds River	1,053
Exploits River	4,810

3.2 AMBIENT WATER QUALITY

Environment and Climate Change Canada (ECCC) collects and manages long-term water quality monitoring data through their online data portal. Two stations near the Project Area were identified as regional water quality references. Station NF02YN0001 is located on the Lloyds River at Route 480 and has water quality data available from 2003 to 2019. Station NF02YO0107 is located on the Exploits River near Millertown and has water quality data available from 2003 to 2019. However, no background concentrations of nitrate, ammonia, and cyanide are reported by ECCC stations within the Project Area. Baseline data collection was conducted by Stantec in 2019 within the mine site (Figure 2-1) to evaluate the local water quality of the surface water that flows to the receiving environments of Valentine Lake, Victoria Lake Reservoir and the Victoria River. The initial baseline sampling took place in March 2011 and additional sampling locations were added throughout the baseline monitoring period for a total of 26 locations in 2019. The results of this study are assumed to be representative of the background concentration of nitrate and ammonia in Red Indian Lake. The background concentration of cyanide was assumed to be non-detectable. The un-ionized ammonia (expressed as nitrogen) concentration varied between 0.05 mg/Land of 0.31 mg/L with a mean concentration of 0.09 mg/L. Nitrate concentration varied between 0.05 mg/L and 1.20 mg/L with a mean concentration of 0.11 mg/L. Table 3-3 summarizes un-ionized ammonia and nitrate background concentrations in the lake.

Table 3-3 Summary of Background Concentration of Water Quality Parameters in the Mine Site

Parameter	Units	Min	Max	Mean
Nitrate	mg/l	0.050	1.200	0.110
Un-ionized ammonia	mg/l	0.050	0.310	0.090

3.3 METEOROLOGICAL DATA

3.3.1 Wind Speed and Direction

Hourly wind speed and direction data are available at the Environment Canada (EC) station Millertown RCS (ID 8402757) located approximately 7 km northeast of the Exploits River Dam. The wind rose map for the data measured during the period between January 2013 and July 2020 is shown in Figure 3-6. The maximum and average measured wind speeds were 10.83 m/s and 1.94 m/s, respectively. According to Figure 3-6, the dominant wind direction is from the southwest (225°).

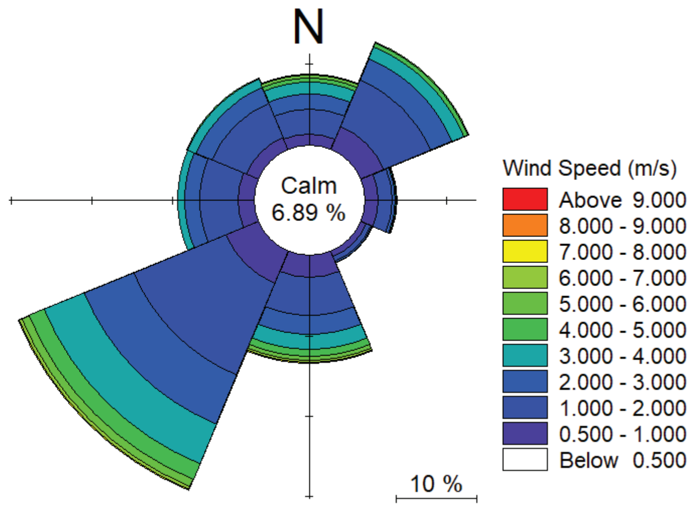

Figure 3-6 Wind Speed and Direction at EC Station Millertown RCS (ID 8402757) for the Period 2013 to 2020

4.0 HAZARDOUS MATERIAL INFORMATION

4.1 DIESEL FUEL

The most common hydrocarbon that will be transported to the mine site is diesel fuel. Petroleum-derived diesel is composed of about 75% saturated hydrocarbons (primarily paraffin including n, iso, and cycloparaffins), and 25% aromatic hydrocarbons (including naphthalenes and alkylbenzenes) (Bacha et al. 2007). The average chemical formula for common diesel fuel is $C_{12}H_{24}$, ranging approximately from $C_{10}H_{20}$ to $C_{15}H_{28}$ (Petro Canada 2020). Diesel will be delivered to the mine site by tanker truck from Grand Falls-Windsor, and it is expected to be transported to the mine site on a year-round basis on semi-tractor / tanks with maximum capacity up to 43,900 litres. A background review was conducted to identify the historical spills that occurred in Canada. The spill volumes reported in the review was between 3,000 litres and 23,000 litres (Marychuk 2020; Tam 2013; CBC News 2014; Serrano et al. 2019; The Leader 2011). The diesel spill volume used in this study is 12,000 litres within an hour.

4.2 SODIUM CYANIDE

Sodium cyanide is a poisonous compound with the formula NaCN (molar mass: 49.0072 g/mol). Cyanide (molar mass: 26.018 g/mol) has a high affinity for metals and leads to the high toxicity of this salt, which accounts for 53 percent of Sodium cyanide based on the molar mass (National Research Council 1994; Sigma-Aldrich 2020; CSBP Limited 2020). Its main application, in gold mining, also exploits its high reactivity toward metals and is used as a gold leaching agent. Sodium is a relatively environmentally benign product and does not negatively impact water quality.

Sodium cyanide transport will be in accordance with the International Cyanide Management Code (ICMC) for the gold mining industry. It will be delivered to the mine site in briquette form and is most typically shipped in 50 kg drums or 100 kg plywood boxes in 20-tonne shipments. Cyanide can be spilled from tankers, trains, and helicopters mostly in briquette form and rarely in pellet form. A background review was conducted to identify the historical spill range for NaCN. The spill range is reported between 9 kg and 1,800 kg from the review (Brown 1988; Australian Government 2008; CBC News 2010; Head 2012; Benjamin 1986; Dunstan 2006; Australian Gold Reagents Pty Ltd 1995). NaCN packaging and transport is stringently controlled through the ICMC, with redundancy measures for containment. As a result of stringent product containment controls, the likelihood of a NaCN release to the Victoria River is extremely low. However, the assumed mass of NaCN released to the Victoria River for the purposes of this study was approximately one single transport drum (i.e., 47 kg) within an hour.

4.3 AMMONIUM NITRATE

Ammonium nitrate is a chemical compound with the chemical formula NH_4NO_3 (molar mass: 80.043 g/mol). Nitrate (molar mass: 62.004 g/mol) accounts for 77 percent of ammonium nitrate based on the molar mass (PubChem, 2020; Ammonium Nitrate, 2020). Ammonium nitrate is a white crystalline solid, highly soluble in water, that is predominantly used in agriculture, mining, quarrying and civil construction.

Ammonium nitrate is the primary component of ANFO (Ammonium Nitrate Fuel Oil), and ammonium nitrate emulsion explosives with the latter are considered the primary explosive to be used at the mine site (AN Prill 2020; Fortis Extra System 2020). ANFO has no water resistance and is readily soluble. Emulsion, on the other hand, is a combination of liquefied ammonium nitrate in a fuel/wax matrix providing the required water resistance; this emulsion will be manufactured on the mine site.

The ammonium nitrate is transported in prill / flaked (solid) form, in 1000 kg bags in shipping containers. The Project will have an explosive manufacturing facility where the solid form ammonia prill will be transformed into a solution using steam and water and subsequently emulsified for use. Limited spill information was available for ammonium nitrate, and the volume of ammonia nitrate released to the Victoria River in this study was set at 108.70 kg within an hour, assuming the puncture and release of material from one 1000 kg transport bag.

4.4 REGULATORY FRAMEWORKS

The Metal and Diamond Mining Effluent Regulation (MDMER) provides the analytical requirements and limits to reduce threats to fish and their habitat by improving the management of harmful substances in metal and diamond mining effluent. Although the MDMER is used to define effluent criteria, it was used in this study as a guide to set toxicity thresholds. The Canadian Council of Ministers of the Environment (CCME) CWQG-FAL[1] provides science-based goals for the quality of aquatic and terrestrial ecosystems. Un-ionized ammonia concentration is reported at pH 7.5, temperature 15°C, which is the lowest expected value for the Project Area. The analytical requirements and limits for cyanide, un-ionized ammonia, and nitrate are summarized in Table 4-1.

Table 4-1 MDMER and CEQGs Allowable Concentration Limits

Parameter	MDMER (mg/l)	CCME CWQG-FAL (mg/l)
Cyanide[1]	2.000	0.005
Un-ionized ammonia (expressed as nitrogen)[2]	1.000	1.83
Nitrate	N/A	550[3]
Diesel	-	-

Notes:
[1] Maximum Authorized Concentration in a Grab Sample
[2] Ammonia concentration under different pH and temperature, See table at: http://st-ts.ccme.ca/en/index.html?chems=5&chapters=1
[3] 550 mg/l for short term exposure and 13 mg/l for long term exposure.

[1] Canadian Water Quality Guidelines for the Protection of Freshwater Aquatic Life (CWQG-FAL)

5.0 MODELLING APPROACH AND SETUP

5.1 MODEL DESCRIPITION

A two-dimensional (2D) hydrodynamic model was built using MIKE 21 Flow Model Flexible Mesh (FM) (DHI 2017). MIKE 21 is a powerful commercial 2D finite volume model that solves the 2D incompressible Reynolds averaged Navier-Stokes equations under the Boussinesq and hydrostatic pressure assumptions. The model consists of continuity, momentum and density equations and considers a turbulent closure scheme. The MIKE 21 model inputs included horizontal eddy viscosity, flow, water level boundary conditions, and wind speed and direction. Shown in Figure 2-2, the model domain included a portion of the lake where a release would spread a plume due to an accidental spill of diesel, sodium cyanide and ammonium nitrate. As explained in Sections 3.1 and 3.2, available provincial and federal records of water level and flow data were analyzed to evaluate low, high, seasonal flow and water level conditions within the study area. Water levels at WSC station 02YO017 were analyzed and used as the downstream boundary condition of the MIKE21 FM model. Flow at WSC station 02YO016 was used to estimate inflows to the lake from the watercourses flowing into the lake. Inflows to the lake were the upstream boundary condition of the MIKE 21 model.

Once the 2D hydrodynamic model was built, MIKE 21 Particle Tracking (PT), which is an add on to the MIKE21 FM, was used to model diesel, sodium cyanide and ammonium nitrate spills to the Victoria River into Red Indian Lake. The MIKE 21 PT module is used for modelling of transport and fate of dissolved, suspended and sedimented substances discharged or accidently spilled in rivers and lakes. The particle or substances may be a pollutant, conservative or non-conservative. The MIKE 21 PT module inputs included horizontal dispersion coefficient and decay rate. Horizontal dispersion coefficients were considered in the dispersion module using a scaled eddy viscosity formulation, which allowed the model to adjust the vertical and horizontal dispersion as flow condition changes. A point source was added at the location of the access road bridge over the Victoria River, where an accidental spill was modelled to occur. Estimated flux and concentration of the accidental diesel, sodium cyanide and ammonium nitrate spills were assigned to the point source.

Figure 5-1 presents MIKE 21 computational mesh and bathymetry with 8,378 elements. The bathymetric data published by Environment Canada in a report written by Morry and Cole was used to build the model bathymetry (Cole 1997).

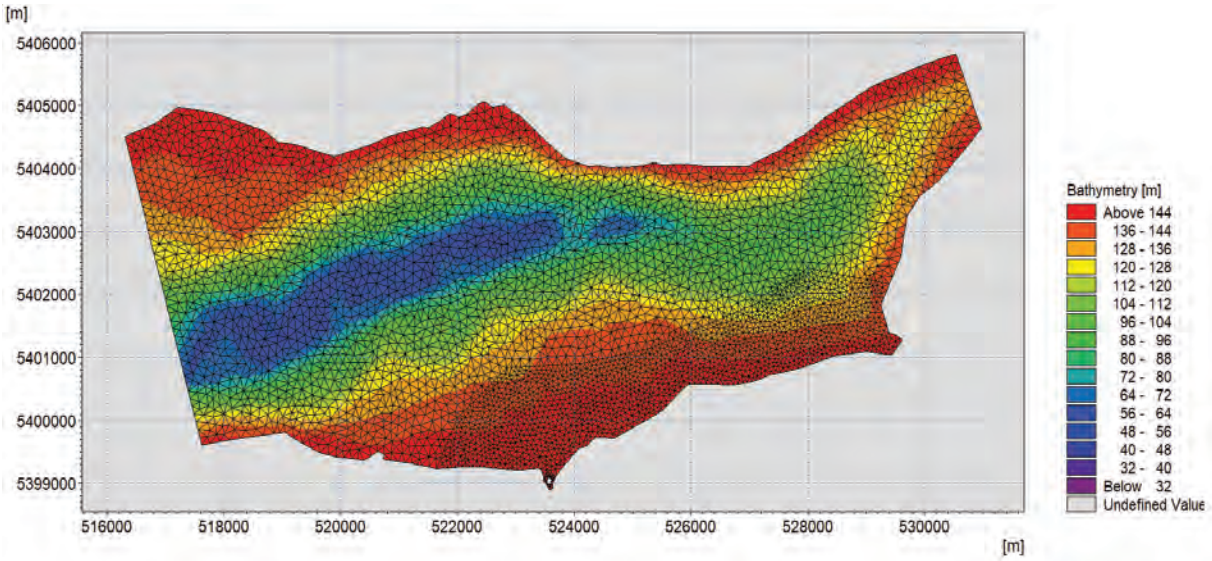

Figure 5-1 MIKE 21 FM Model Domain

5.2 MODELLING SCENARIOS

The annual minimum 7-day average (7Q1), the mean annual flow, and the 1:30 year high flow (Q30) were considered as three potential flow scenarios to estimate the inflow from each watercourse into the lake. Represented in Section 3.2, low-flow and peak-flow frequency analyses were conducted to estimate the annual minimum 7-day average streamflow and the 1:30 year high flow. Flow scenarios and the estimated inflow from each watercourse are summarized in Table 5-1.

Table 5-1 Flow Scenarios to Red Indian Lake

Modelling Scenario	Water Level (m)	Wind Speed and Direction	Victoria River (m^3/s)	West Inflow (m^3/s)	East Inflow (m^3/s)
Scenario 1	Annual 7 day low (151.30)	Calm	7Q1 (7.9)	7Q1 (27.8)	7Q1 (8.9)
Scenario 2	Mean annual (153.68)	Average wind speed (1.94 m/s); wind direction from the southwest	Mean annual (17.6)	Mean annual (61.8)	Mean annual (19.8)
Scenario 3	Monthly annual maximum (156.39)	Calm	Q30 (164.3)	Q30 (576.9)	Q30 (184.3)

5.3 HAZARDOUS MATERIALS SPILL ASSUMPTION

Diesel

An estimated 12,000 L of diesel fuel was assumed to spill into the Victoria River within an hour. Diesel density varies between 820 kg/m^3 and 950 kg/m^3. An average density of 885 kg/m^3 was assumed for the modelling purposes.

Decay rate was defined in the model setup as a constant to estimate diesel evaporation and volatilization as a function of time. MIKE Oil Spill scientific documentation suggests 10 to 30 percent mass reduction due to evaporation and volatilization for diesel (DHI 2019). Therefore, a 20% decay rate was considered in the MIKE 21 PT module to estimate diesel evaporation and volatilization.

Sodium Cyanide

Sodium is a relatively environmentally benign product, and therefore only cyanide was modelled in this study. It was assumed that 47 kg of one barrel of sodium cyanide spilled into the Victoria River within an hour. The amount of cyanide was then calculated using the molar mass analysis in Section 4.2. Since 53% of sodium cyanide is cyanide, the total cyanide mass of 25 kg was considered to spill into the Victoria River over an hour. No decay and settlement rates were considered in the model to create the worst-case conditions.

Ammonium Nitrate

Ammonia and nitrate were simulated separately as ammonium nitrate dissociates in the water. The total amount of spilled ammonium nitrate was assumed to be 108.70 kg within an hour. Therefore, the total amount of spilled ammonia and nitrate were 25 kg and 83.75 kg, respectively, within an hour (see Section 4.3). No decay and settlement rates were considered for either ammonia or nitrate.

6.0 RESULTS AND DISCUSSION

6.1 CYANIDE AND AMMONIA CONCENTRATIONS

According to Section 3.2, the background concentration of cyanide was assumed to be non-detectable. The MDMER and CWQG-FAL limits for cyanide concentration are 2 mg/l and 0.005 mg/l, respectively (see Table 4-1). The background ammonia concentration ranged from 0.05 mg/l to a maximum of 0.31 mg/l and had a mean of 0.09 mg/l. The MDMER and CWQG-FAL limits for ammonia concentration are 1 mg/l and 1.83 mg/l, respectively (see Table 4-1). The maximum background ammonia concentration was below the MDMER and CWQG-FAL limits in the Project Area. In the following, the total cyanide concentration refers to the background concentration of cyanide, as well as the simulated cyanide concentration after the spill (same for the total ammonia concentration).

6.1.1 Scenario 1

Figure 6-1a to Figure 6-1e show the simulation results for cyanide concentration at the beginning, 1 day, 7 days, 14 days, and 21 days after the spill. At the beginning of the simulation when the spill was modelled to occur in the Victoria River, the maximum cyanide concentration was 2.6 mg/l, which was above the CWQG-FAL and MDMER limits (see Figure 6-1a). Shown in Figure 6-1b, after one day of simulation, the plume concentration reduced below 0.1 mg/l, approximately, due to assimilative with the ambient water. Figure 6-1b shows that the total concentration of cyanide reached below the MDMER limit after one day. Shown in Figure 6-1e, the plume reached the Exploits River Dam within 3 weeks after the spill, with a maximum total concentration of 0.013 mg/l that was below the MDMER limit but slightly above the CWQG-FAL limit. It is expected that the ammonia concentration follows the same behaviour. The maximum total ammonia concentration immediately after the spill was 2.69 mg/l, which was above the MDMER and CWQG-FAL limits (see Figure 6-1a). Shown in Figure 6-1b, the plume concentration reached below the CWQG-FAL limit after one day. The plume reached the Exploits River Dam within 3 weeks after the spill, with a maximum concentration of 0.103 that was below the MDMER and CWQG-FAL limits.

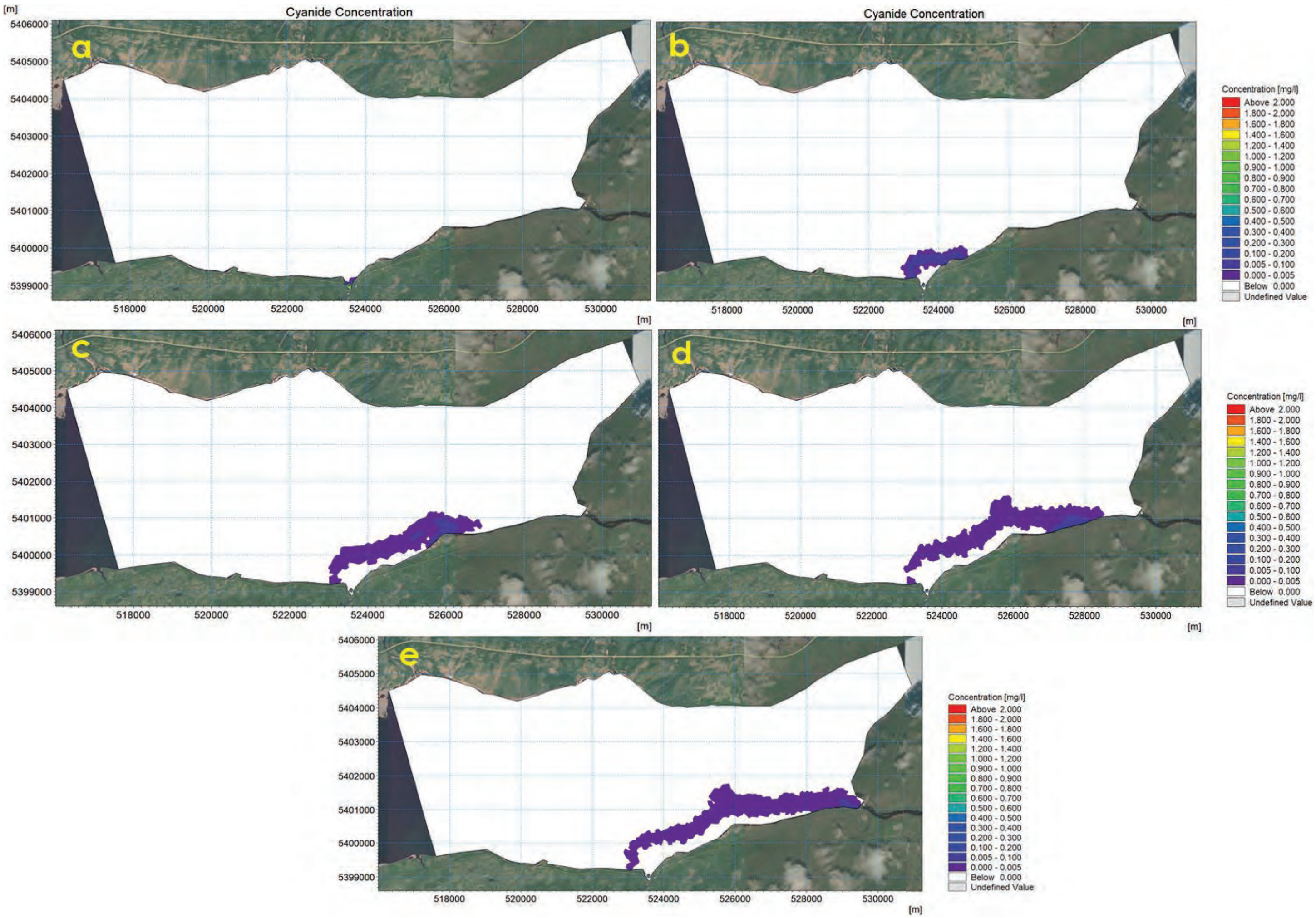

Figure 6-1 Scenario 1 - Cyanide Concentration Results: a) At the Beginning of the Spill, b) 1 Day after the Spill, c) 7 Days after the Spill, d) 14 Days after the Spill, e) 21 Days after the Spill

6.1.2 Scenario 2

Figure 6-2a to Figure 6-2d present the total cyanide concentration at the beginning, 1 day, 2 days, and 2.5 days after the spill. In this scenario, the water level was increased by 2.38 m compared to Scenario 1 (see Table 5-1). In addition, the mean annual flow was considered to determine the inflow from each watercourse, and as a result, the inflow values in Scenario 2 increased by 122% compared to Scenario 1. The average wind speed of 1.94 m/s was considered in Scenario 2. The simulation results revealed that the plume reached the dam faster and moved closer to the shoreline compared to Scenario 1 due to the increased flow rate and wind action (see Figure 6-1e and Figure 6-2e). According to Figure 6-1and Figure 6-2, the plume dispersion into the lake decreased compared to Scenario 1 due to wind action. The maximum initial concentration of cyanide was 2 mg/l, which satisfied the MDMER limit but was above the CWQG-FAL limit (see Figure 6-2a). According to Figure 6-1a and Figure 6-2a, the initial plume concentration decreased in Scenario 2 due to the higher mixing rate. The plume reached the dam after 2.5 days, with a maximum total concentration of 0.07 that was below the MDMER limit but slightly higher than the CWQG-FAL limit (see Figure 6-2d). It is expected that the ammonia concentration follows the same behaviour. The maximum total ammonia concentration immediately after the spill was 2.09 mg/l, which was above the MDMER and CWQG-FAL limits (see Figure 6-2a). Shown in Figure 6-2d, the plume reached the dam after 2.5 days, with a maximum of 0.16 mg/l that reached below the MDMER and CWQG-FAL limits.

6.1.3 Scenario 3

Figure 6-3a to Figure 6-3c show the total cyanide concentration at the beginning, 1 day, and 1.5 days after the spill. In this scenario, the water level was increased by 2.71 m and 5.09 m compared to Scenario 2 and Scenario 1, respectively (see Table 5-1). The 1:30 year high flow was considered to determine the inflow from each watercourse resulting in an 833% and a 1975% flow increment compared to Scenario 2 and Scenario 1, respectively (see Table 5-1). The wind condition was considered the same as Scenario 1 (calm). According to Figure 6-3a, the maximum total concentration of cyanide immediately after the spill was 0.21 mg/l, which was below the MDMER limit but above the CWQG-FAL limit. The increased water level and flow rate enhanced the volume of water, and therefore the mixing rate of cyanide with water, that reduced the initial plume concentration compared to Scenarios 1 and 2 (see Figure 6-1a, Figure 6-2a and Figure 6-3a). Shown in Figure 6-2 and Figure 6-3, the plume dispersion into the lake increased compared to Scenario 2. The plume dispersion pattern was different compared to Scenario 2, with a higher plume concentration at the dam (see Figure 6-1and Figure 6-3). According to Figure 6-3c, the plume reached the dam after 1.5 days with a maximum total concentration of 0.004 mg/l, which was below the MDMER and CWQG-FAL limits. It is expected that the ammonia concentration follows the same behaviour. The maximum initial ammonia concentration 0.3 mg/l was below the MDMER and CWQG-FAL limits (see Figure 6-3a). Shown in Figure 6-3c, the plume reached the dam after 1.5 days.

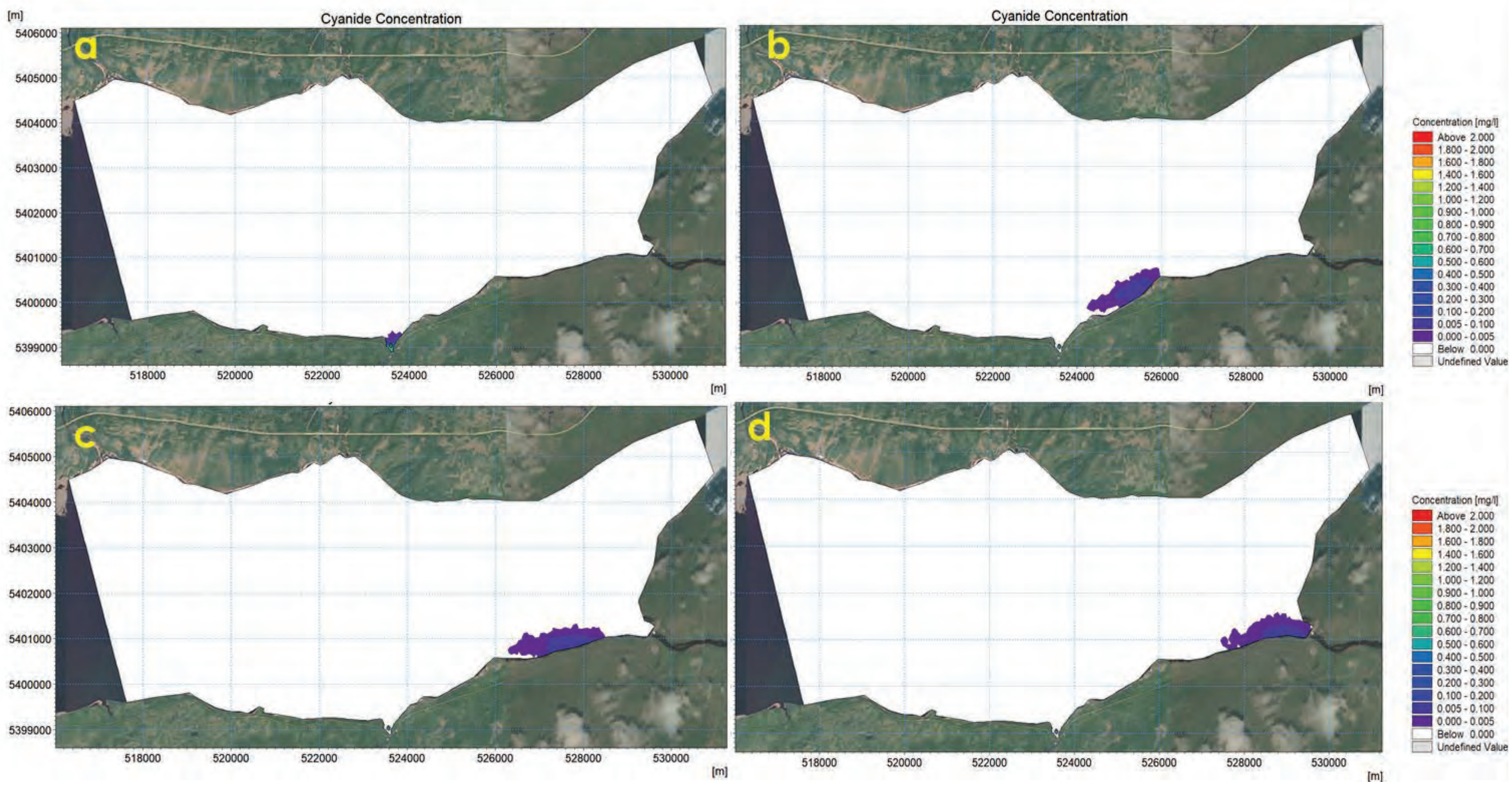

Figure 6-2 Scenario 2 - Cyanide Concentration Results: a) At the Beginning of the Spill, b) 1 day After the Spill, c) 2 Days After the Spill, d) 2.5 Days After the Spill

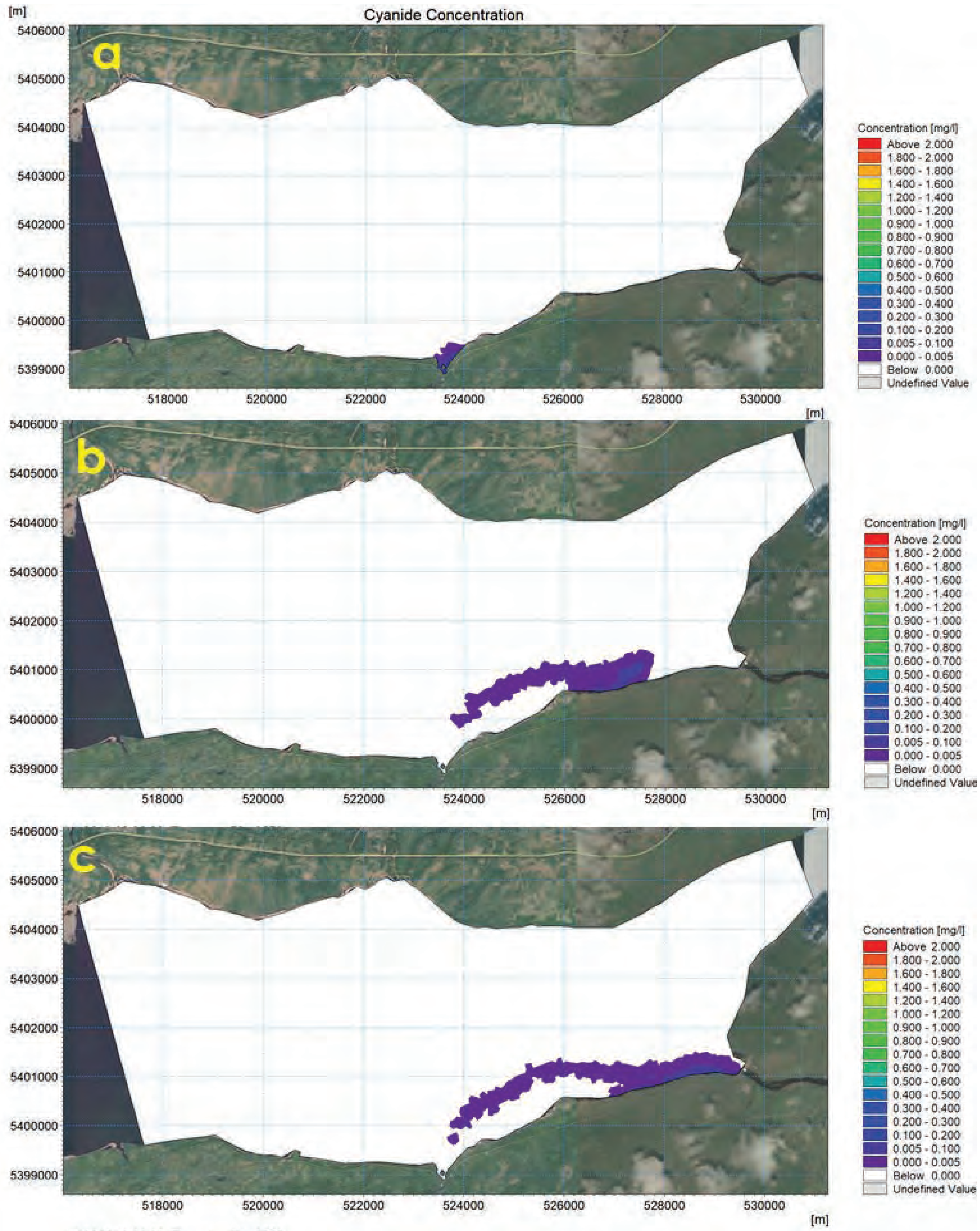

Figure 6-3 Scenario 3 - Cyanide Concentration Results: a) At the Beginning of the Spill, b) 1 Day After the Spill, c) 1.5 Days After the Spill

6.2 NITRATE CONCENTRATION

According to Table 3-3, the background concentration of nitrate in the lake ranged from 0.05 mg/l to a maximum of 1.2 mg/l and had a mean of 0.11 mg/l. Summarized in Table 4-1, short-term and long-term CWQG-FAL limits for nitrate concentration are 550 mg/l and 13 mg/l, respectively. No MDMER concentration limit is reported for nitrate. The maximum background concentration of nitrate was below the CWQG-FAL limit in the Project Area. In the following, the total nitrate concentration refers to the mean background concentration of nitrate, as well as the simulated nitrate concentration after the spill.

6.2.1 Scenario 1

Figure 6-4a to Figure 6-4e show the total nitrate concentration simulation results at the beginning, 1 day, 7 days, 14 days, and 21 days after the spill. At the beginning of the simulation, the maximum total nitrate concentration was 9.11 mg/l, which was below short-term and long-term CWQG-FAL limits (see Figure 6-4a). Shown in Figure 6-4e, the plume reached the Exploits River Dam within 3 weeks after the spill. The dispersion pattern of nitrate followed the same behaviour as cyanide (see Figure 6-1 and Figure 6-4). The initial concentration of nitrate was higher than cyanide as a larger amount of nitrate (83.75 kg) spilled into the river was modelled compared to cyanide (25 kg).

6.2.2 Scenario 2

Figure 6-5a to Figure 6-5d present the nitrate concentration at the beginning, 1 day, 2 days, and 2.5 days after the spill. In this scenario, the water level was increased by 2.38 m compared to Scenario 1 (see Table 5-1). In addition, the mean annual flow was considered to determine the inflow from each watercourse, and as a result, the inflow values in Scenario 2 increased by 122% compared to Scenario 1. The average wind speed of 1.94 m/s was considered in Scenario 2. The simulation results revealed that the plume reached the dam faster and moved closer to the shoreline compared to Scenario 1 due to the increased flow rate and wind action (see Figure 6-4 and Figure 6-5). According to Figure 6-4 and Figure 6-5, the plume dispersion into the lake decreased compared to Scenario 1 due to wind action. The maximum total concentration of nitrate immediately after the spill was 2.41 mg/l, which was below the short-term and long-term CWQG-FAL limits (see Figure 6-5a). According to Figure 6-4a and Figure 6-5a, the initial plume concentration decreased in Scenario 2 due to the higher mixing rate. Shown in Figure 6-5d, the plume reached the dam after 2.5 days, with a maximum total of 0.35 mg/l. The dispersion pattern of nitrate followed the same behaviour as cyanide (see Figure 6-2 and Figure 6-5).

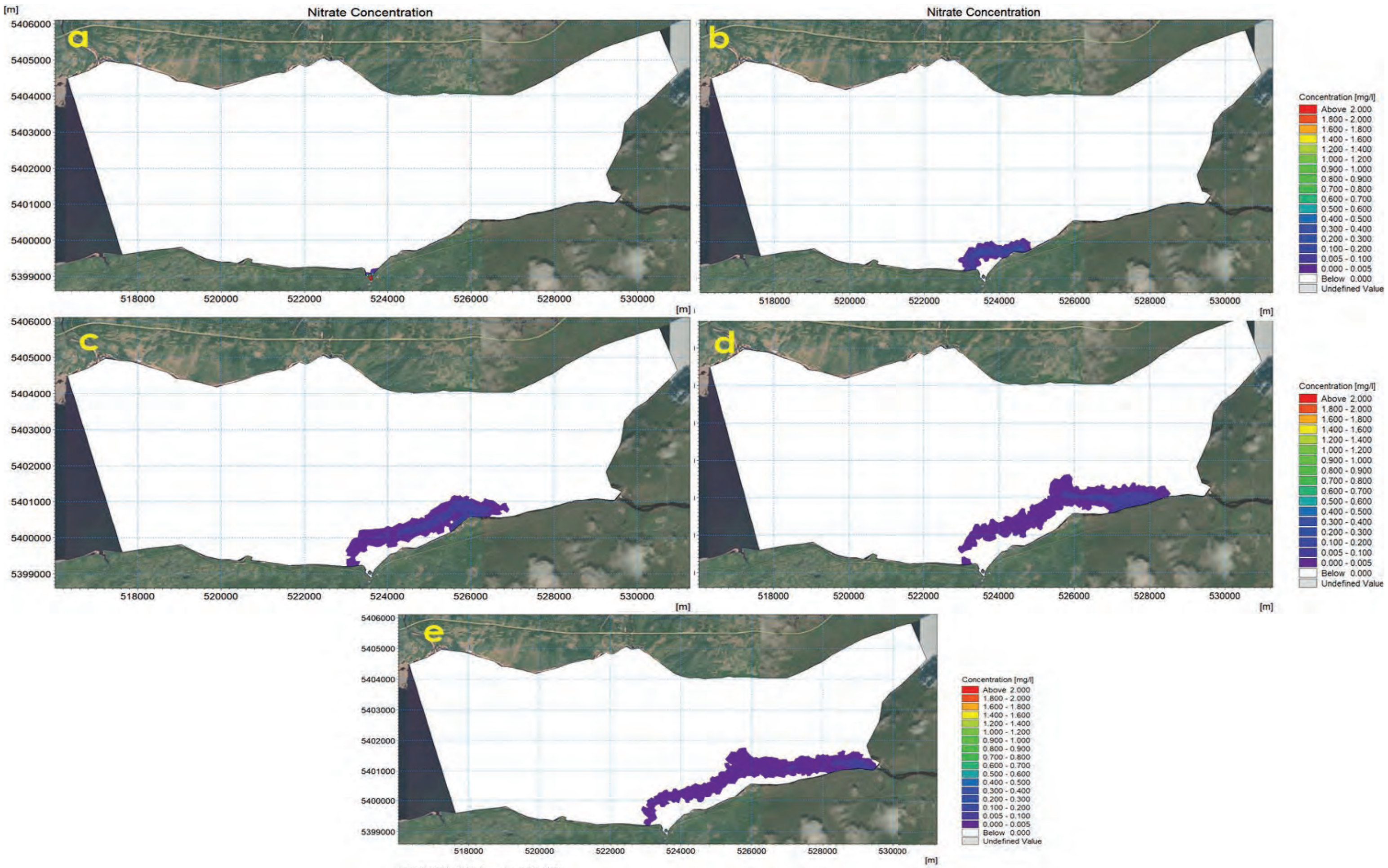

Figure 6-4 **Scenario 1 - Nitrate Concentration Results: a) At the Beginning of the Spill, b) 1 Day After the Spill, c) 7 Days After the Spill, d) 14 Days After the Spill, e) 21 Days After the Spill**

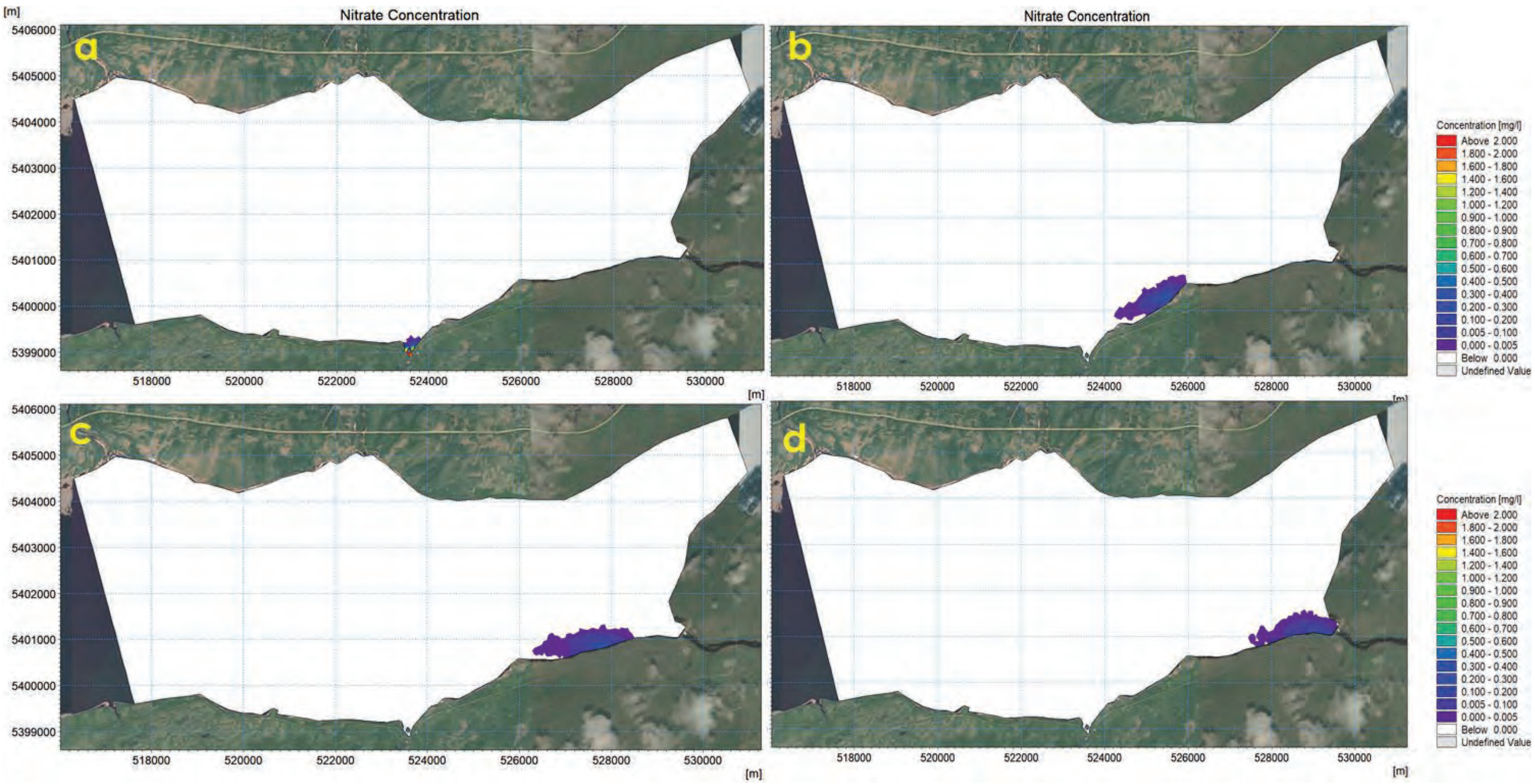

Figure 6-5 Scenario 2 - Nitrate Concentration Results: a) At the Beginning of the Spill, b) 1 day After the Spill, c) 2 Days after the Spill, d) 2.5 days After the Spill

6.2.3 Scenario 3

Figure 6-6a to Figure 6-6c show the nitrate concentration at the beginning, 1 day, and 1.5 days after the spill. In this scenario, the water level was increased by 2.71 m and 5.09 m compared to Scenario 2 and Scenario 1, respectively (see Table 5-1). The 1:30 year high flow was considered to determine the inflow from each watercourse resulting in an 833% and a 1975% flow increment compared to Scenario 2 and Scenario 1, respectively (see Table 5-1). The wind condition was considered the same as Scenario 1 (calm). The maximum total concentration of nitrate immediately after the spill was 0.39 mg/l and below short-term and long-term CWQG-FAL limits (see Figure 6-6a). The increased water level and flow rate enhanced the volume of water, and therefore the mixing rate of nitrate with water in this scenario, which reduced the initial plume concentration compared to Scenarios 1 and 2 (see Figure 6-4a, Figure 6-5a and Figure 6-6). Shown in Figure 6-5 and Figure 6-6, the plume dispersion into the lake increased compared to Scenario 2. The plume dispersion pattern was different compared to Scenario 2, with an increased plume concentration at the dam (see Figure 6-4 and Figure 6-6). Shown in Figure 6-6c, the plume reached the dam after 1.5 days, with a maximum total concentration of 0.125 mg/l. The dispersion pattern of nitrate followed the same behaviour as cyanide (see Figure 6-3 and Figure 6-6).

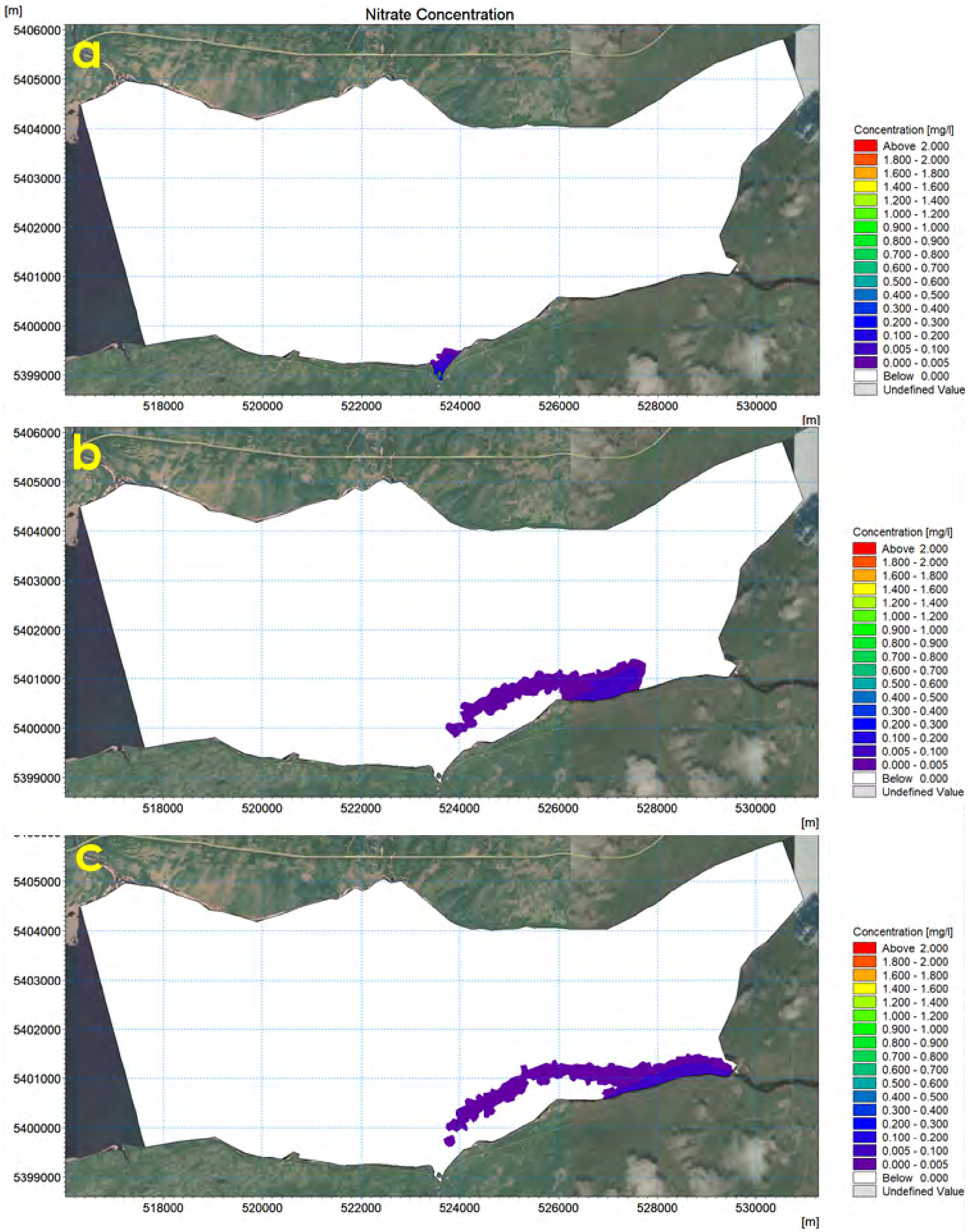

Figure 6-6 Scenario 3 - Nitrate Concentration Results: a) At the Beginning of the Spill, b) 1 day After the Spill, c) 1.5 Days After the Spill

6.3 DIESEL CONCENTRATION

6.3.1 Scenario 1

Figure 6-7a to Figure 6-7e show the diesel concentration simulation results at the beginning, 1 day, 7 days, 14 days, and 21 days after the spill. According to Table 4-1, no MDMER and CWQG-FAL concentration limits are reported for diesel. Shown in Figure 6-7a, the maximum initial concentration of diesel was 1100 mg/l. The plume concentration reached below 1 mg/l after a week (see Figure 6-7c). The dispersion pattern of diesel followed the same behaviour as nitrate and cyanide (see Figure 6-1, Figure 6-4, and Figure 6-7). The plume reached the dam after 21 days, with a maximum concentration of 0.11 mg/l.

6.3.2 Scenario 2

Figure 6-8a to Figure 6-8d present the diesel concentration at the beginning, 1 day, 2 days, and 2.5 days after the spill. In this scenario, the water level was increased by 2.38 m compared to Scenario 1 (see Table 5-1). In addition, the mean annual flow was considered to determine the inflow from each watercourse, and as a result, the inflow values in Scenario 2 increased by 122% compared to Scenario 1. The average wind speed of 1.94 m/s was considered in Scenario 2. Shown in Figure 6-7 and Figure 6-8, the simulation results revealed that the plume reached the dam faster and moved closer to the shoreline compared to Scenario 1 due to the increased flow rate and wind action. According to Figure 6-7 and Figure 6-8, the plume dispersion into the lake decreased compared to Scenario 1 due to wind action. The maximum initial concentration of diesel was 285 mg/l, which was reduced compared to Scenario 1 due to the higher mixing rate (see Figure 6-7a). The diesel concentration in Scenario 2 was higher than Scenario 1 at the dam (Figure 6-7 and Figure 6-8). Discussed in Section 5.3, a 20 percent decay rate was assumed for diesel. Shorter travel time in Scenario 2 reduced the evaporation and volatilization rate, and therefore, the plume concentration increased at the dam in Scenario 2 compared to Scenario 1 (Figure 6-7 and Figure 6-8). Shown in Figure 6-8d, the plume reached the dam after 2.5 days, with a maximum concentration of 17 mg/l. The dispersion pattern of diesel followed the same behaviour as cyanide and nitrate (Figure 6-1, Figure 6-4, and Figure 6-7).

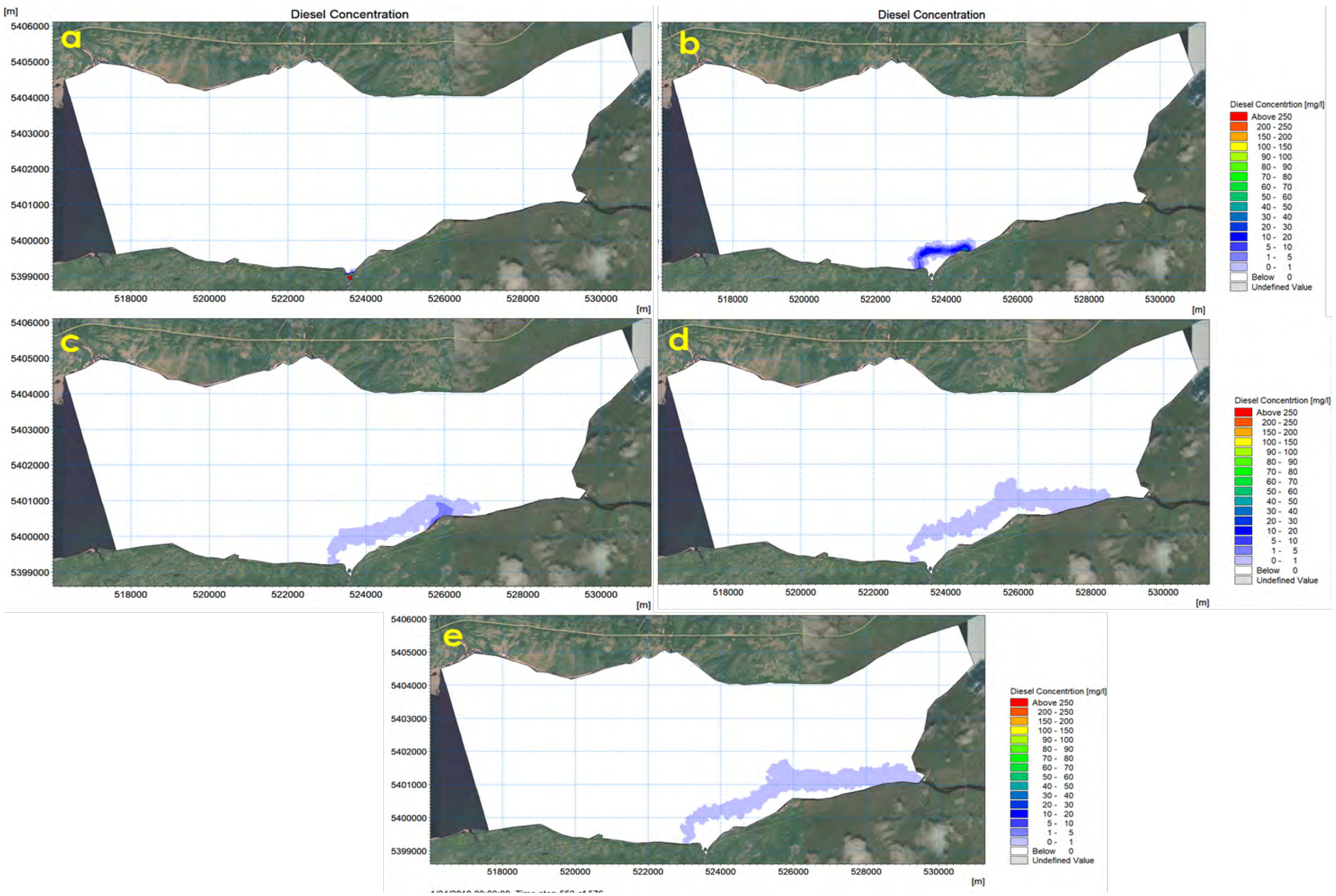

Figure 6-7 Scenario 1 - Diesel Concentration Results: a) At the Beginning of the Spill, b) 1 Day After the Spill, c) 7 Days After the Spill, d) 14 Days After the Spill, e) 21 Days After the Spill

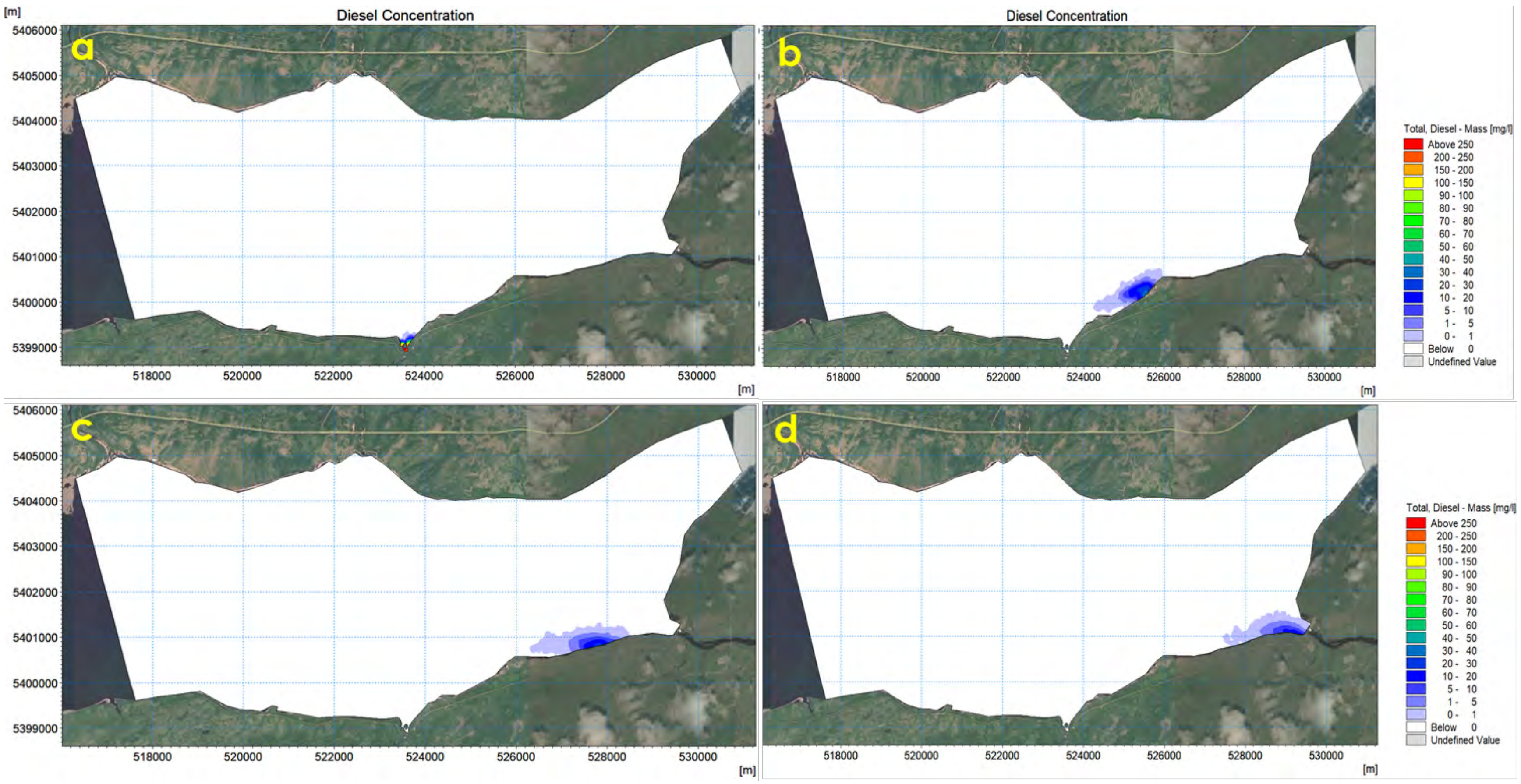

Figure 6-8 Scenario 2 - Diesel Concentration Results: a) At the Beginning of the Spill, b) 1 Day After the Spill, c) 2 Days After the Spill, d) 2.5 Days After the Spill

6.3.3 Scenario 3

Figure 6-9a to Figure 6-9c show the diesel concentration at the beginning, 1 day, and 1.5 days after the spill. In this scenario, the water level was increased by 2.71 m and 5.09 m compared to Scenario 2 and Scenario 1, respectively (see Table 5-1). The 1:30 year high flow was considered to determine the inflow from each watercourse resulting in an 833% and a 1975% flow increment compared to Scenario 2 and Scenario 1, respectively (see Table 5-1). The wind condition was considered the same as Scenario 1 (calm). The maximum initial concentration of diesel was 28 mg/l (see Figure 6-9a). According to Figure 6-7a, Figure 6-8a, and Figure 6-9a, the increased water level and flow rate enhanced the volume of water, and therefore the mixing rate of diesel with water, which reduced the initial plume concentration compared to Scenarios 1 and 2. The plume dispersion into the lake increased compared to Scenario 2 (see Figure 6-8 and Figure 6-9). The plume dispersion pattern was different compared to Scenario 1, with a higher plume concentration at the dam (Figure 6-7 and Figure 6-9). According to Figure 6-3, Figure 6-6, and Figure 6-9, the dispersion pattern of diesel followed the same behaviour as nitrate and cyanide. Shown in Figure 6-9c, the maximum plume concentration reached to 1.2 mg/l at the dam after 1.5 days.

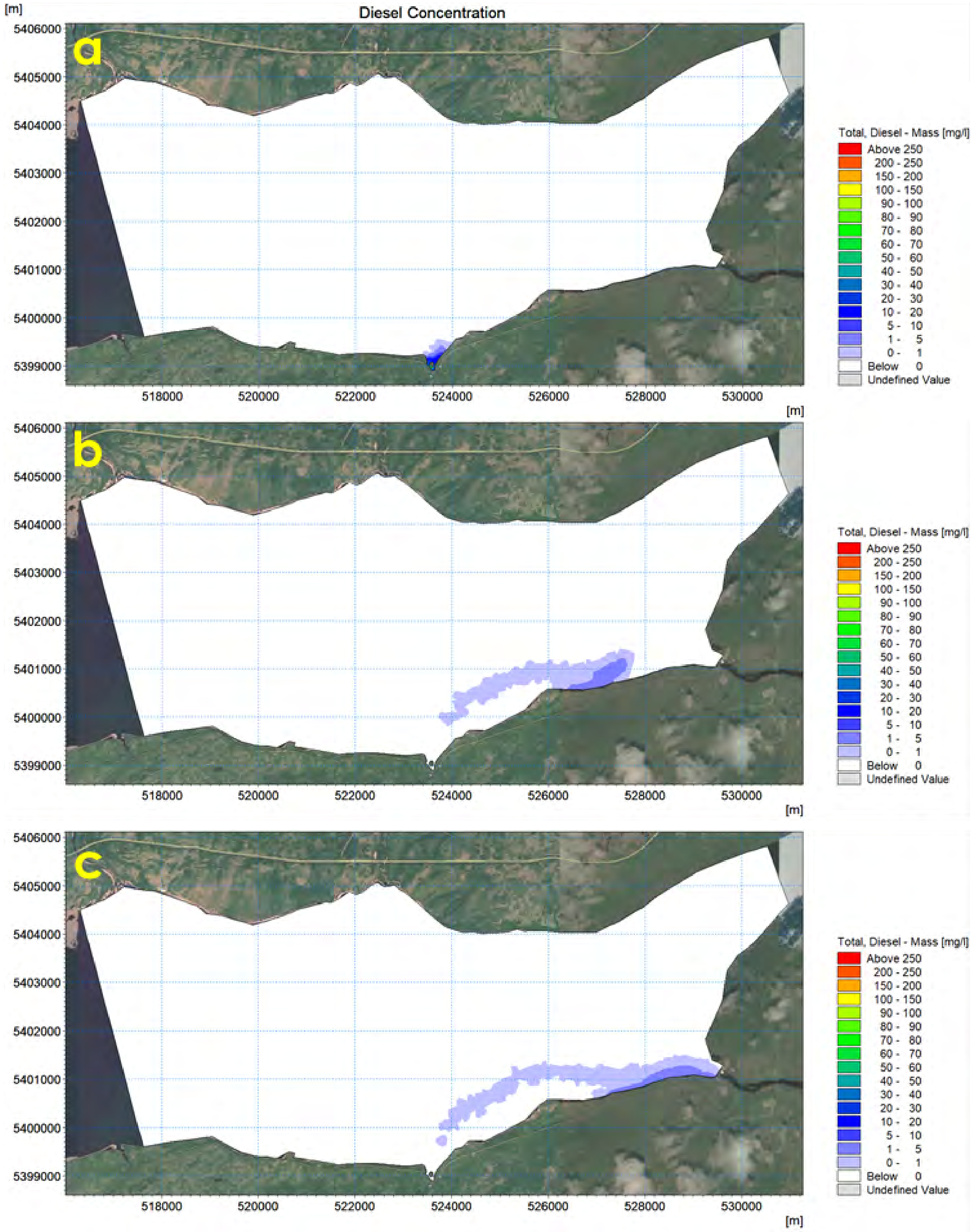

Figure 6-9 Scenario 3 - Diesel Concentration Results: a) At the Beginning of the Spill, b) 1 Day After the Spill, c) 1.5 Days After the Spill

7.0 Summary of Findings

The potential impacts of the accidental spills of diesel, sodium cyanide, and ammonium nitrate on the water quality of Red Indian Lake and Victoria River were evaluated under three modelling scenarios. In Scenario 1, the MDMER limits representing toxicity thresholds were exceeded for cyanide and ammonia. However, the duration of exceedances ranged from 5 to 7 days and did not persist. The MDMER limit was exceeded for ammonia in Scenarios 1 and 2, but the exceedance was not persistent, and the total ammonia concentration reached below the MDMER limit after 1 day.

The CWQG-FAL limits representing the water quality thresholds were exceeded for cyanide and ammonia in Scenarios 1 and 2. However, the exceedance was not persistent for ammonia, and the total ammonia concentration reached below the CWQG-FAL limits from 2 to 7 days. The maximum total concentrations of cyanide remained slightly above the CWQG-FAL limit in Scenarios 1 and 2.

Cyanide, ammonia and nitrate are not expected to persist in the environment, nor result in potential bioaccumulation. Diesel may attach to nearshore and shoreline vegetation and shallow sediments, and thus, the potential exists for some further persistence of diesel in the environment. None of the fate and behaviour modelling scenarios considered spill response, particularly for diesel, where the deployment of spill diversion, collection and sorbent booms and product recovery would be reasonably implemented. Thus, the modelling is considered to be conservative and represent a worse-case condition.

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